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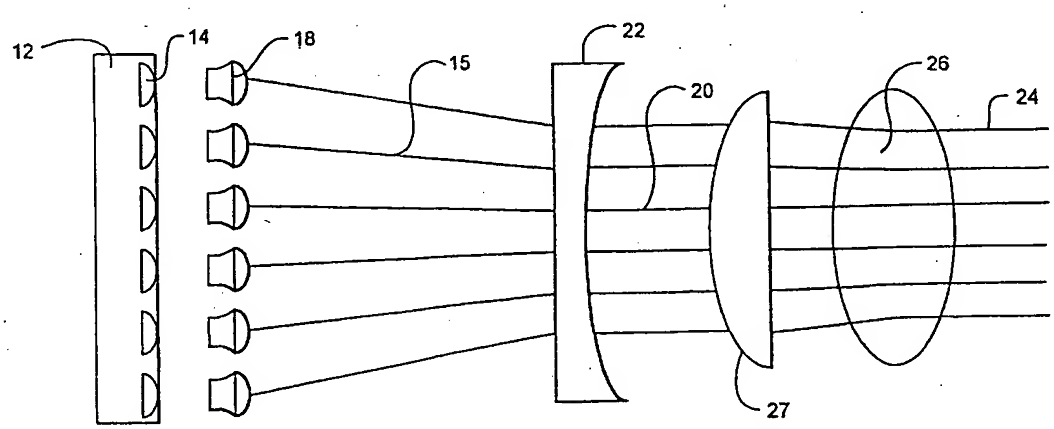

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(57) Abstract

An optical assembly includes a stack of diode linear arrays that produce a produce a plurality of line output beams. A first plurality of microlensesor are positioned adjacent to the stack to collimate and steer the plurality of line output beams and form a single line sourceses through. The other half

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DIRECT DIODE LASER WITH FIBER DELIVERY

BACKGROUND OF THE INVENTION

Field of the Invention

This invention relates generally to stack diode linear arrays, and more particularly to optical assemblies using stack diode linear arrays to form a single line source.

Description of Related Art

The asymmetry of a single diode array produces an output that is difficult to couple into a fiber or other optical elements, including but not limited to gain media. While the m^2 in the vertical direction (the fast axis) is close to unity the m^2 in the horizontal direction (the slow axis) can approach 1000. Power can be scaled by stacking linear arrays which degrades the m^2 in the vertical direction. For every additional stack of linear array the output becomes more problematic to couple into fibers and optical elements.

One application of stacked diode arrays is as a pump source from slab lasers. In this embodiment, the optical cavity of the laser transforms the poor beam quality pump light of the stacked diode array into high beam quality laser output. In other applications, the stacked diode array is used to direct a high amount of power into a relatively large area such as in soldering and welding. In one medical device, the output of the stacked diode array is coupled through a tapered lens duct which directs the light into an area approximately half the emitting area. However, this reduction in beam size is accompanied by a substantial increase in numerical aperture that exceeds the numerical aperture of commercially available fibers. One example of this beam size reduction is a hair removal device with a 10x10 mm aperture and a numerical aperture of 0.7. Commercially available flexible fibers have maximum diameters of 1.5 mm and numerical apertures of 0.37. This beam quality must be improved by a 20 fold factor in order to be coupled into a flexible fiber.

In most industrial processes, including but not limited to cutting and drilling, the laser intensity must exceed 100 kW/cm^2. This also requires substantial improvement of the beam quality that is available from the stack. A diode based source greater than 500 W average power and 100 kW/cm^2 intensity would make a very useful industrial laser that would compete with existing CO_2 and Nd:YAG lasers. The diode source would have longer life, lower operating costs and be more compact in size than the existing CO_2 and Nd:YAG lasers.

In surgical applications, wavelengths that are strongly absorbed by tissue are preferred and CO_2 lasers have found wide utility. However, once laser power exceeds approximately 100 W the wavelength is less important for surgical efficacy. While it is difficult to scale the power of a single laser, it is relatively easy to increase the power of diodes by stacking. If this output could be coupled to a fiber it would be a powerful surgical tool.

It is known to use electromagnetic radiation in medical application for therapeutic uses such as treatment of skin disorders. For example, U.S. Pat. No. 4,298,005 to Mutzhas describes a continuous ultraviolet lamp with cosmetic, photobiological, and photochemical applications. A treatment based on using the UV portion of the spectrum and its photochemical interaction with the skin is described. The power delivered to the skin using Mutzhas' lamp is described as 150 W/m_2, which does not have a significant effect on skin temperature.

In addition to prior art treatment involving UV light, lasers have been used for dermatological procedures, including Argon lasers, CO_2 lasers, Nd:YAG lasers, copper vapor lasers, ruby lasers and dye lasers. For example, U.S. Pat. No. 4,829,262 to Furumoto, describes a method of constructing a dye laser used in dermatology applications. Two skin conditions which may be treated by laser radiation are external skin irregularities such as local differences in the pigmentation or structure of the skin, and vascular disorders lying deeper under the skin which cause a variety of skin abnormalities including port wine stains, telangiectasias, leg veins and cherry and spider angiomas. Laser treatment of these skin disorders

generally includes localized heating of the treatment area by absorption of laser radiation. Heating the skin changes or corrects the skin disorder and causes the full or partial disappearance of the skin abnormality.

Certain external disorders such as pigmented lesions can also be treated by heating the skin very fast to a high enough temperature to evaporate parts of the skin. Deeper-lying vascular disorders are more typically treated by heating the blood to a high enough temperature to cause it to coagulate. The disorder will then eventually disappear. To control the treatment depth a pulsed radiation source is often used. The depth the heat penetrates in the blood vessel is controlled by controlling the pulse width of the radiation source. The absorption and scattering coefficients of the skin also affect the heat penetration. These coefficients are a function of the constituents of skin and the wavelength of the radiation. Specifically, the absorption coefficient of light in the epidermis and dermis tends to be a slowly varying, monotonically decreasing function of wavelength. Thus, the wavelength of the light should be chosen so that the absorption coefficient is optimized for the particular skin condition and vessel size being treated.

The effectiveness of lasers for applications such as tattoo removal and removal of birth and age marks is diminished because lasers are monochromatic. A laser of a given wavelength may be effectively used to treat a first type of skin pigmentation disorder, but, if the specific wavelength of the laser is not absorbed efficiently by skin having a second type of disorder, it will be ineffective for the second type of skin disorder. Also, lasers are usually complicated, expensive to manufacture, large for the amount of power delivered, unreliable and difficult to maintain.

The wavelength of the light also affects vascular disorder treatment because blood content in the vicinity of the vascular disorders varies, and blood content affects the absorption coefficient of the treatment area.

Oxyhemoglobin is the main chromophore which controls the optical properties of blood and has strong absorption bands in the visible region. More particularly, the strongest absorption peak of oxyhemoglobin occurs at 418 nm

and has a band-width of 60 nm. Two additional absorption peaks with lower absorption coefficients occur at 542 and 577 nm. The total band-width of these two peaks is on the order of 100 nm. Additionally, light in the wavelength range of 500 to 600 nm is desirable for the treatment of blood vessel disorders of the skin since it is absorbed by the blood and penetrates through the skin. Longer wavelengths up to 1000 nm are also effective since they can penetrate deeper into the skin, heat the surrounding tissue and, if the pulse-width is long enough, contribute to heating the blood vessel by thermal conductivity. Also, longer wavelengths are effective for treatment of larger diameter vessels because the lower absorption coefficient is compensated for by the longer path of light in the vessel.

Human skin contains a number of appendages. Vascular and lymphatic channels provide for nutrition, healing and transport. Sweat and sebaceous glands provide respectively for thermal control and lubrication. Pigmented structures provide for sun protection. Hair follicles and individual hairs provide for insulation, protection and individual differentiation.

Growth of each hair is originated by germinative fibroblast cells in the basal layer of the epidermis. The hair grows both outwards and inwards during its growth cycle, and the follicle develops as an encapsulating pouch extending beyond the epidermis and down several millimeters in depth to the subcutaneous fat. Hair remains attached to the base of the follicle, where a capillary network develops to provide nourishment. During the agnogenic growth phase, hair matrix cells divide rapidly and migrate upwards to form the shaft. A subsequent catagenic phase is marked by cessation of mitosis, and the reabsorption of the lower part of the follicle. Capillary nourishment is greatly reduced during this phase. In this or the final telogenic (resting) phase, the hair falls out and a new hair may replace it in a new growth cycle. At any particular time, approximately 10% of scalp hairs will be in telogenic mode.

The growth cycle varies with anatomical location from as little as 3 months for facial hair to as much as 7 years on the scalp. Hair in high

friction pubic areas may be retained by the body as protection and may not shed at all.

The hair follicle consists of a mixture of germinative cells and melanocytes. Sebaceous cells empty into the follicle, providing a lipid-rich environment. The follicle is typically 0.1 mm in diameter and may extend to 4 mm in depth. The average hair diameter within the follicle is 60 μm. Hair itself is generated as an accumulation of dead (keratinized) cells. Structurally it consists of two or three discrete layers, as shown in FIG. 1. The outer cuticle layer consists of a single layer of overlapping flat cells like the scales of a fish. This acts as a protective barrier. An inner cortex layer contains any pigment which may be present (pigment may also reside in melanocytes lining the follicle). Pigment may exist as two melanin forms. Eumelanin is responsible for brown/black coloration and pheomelanin is responsible for red/blonde coloration. Larger, fully developed terminal hairs also contain a core known as the medulla. In the lower follicular region, a bulge is formed where the arrector pili muscle contacts the follicle. This muscle controls movement and orientation of the hair and may, under appropriate stimuli, render the hair vertical with respect to the skin surface. The bulge area has one of the fastest rates of cell division found in mammals, stimulated by growth factors from the lower papilla area.

While the hair follicle and hair contained therein function at several different levels, excess body hair does present a cosmetic problem for hirsute females. As a consequence, many individuals undergo hair removal treatments. Conventional techniques, including electrolysis, shaving, wax epilation and tweezing, are often painful and temporary.

Electrolysis is used by an estimated 1 million women in the United States. Two techniques dominate the electrolysis field. Galvanic (DC) current can be passed down a fine needle inserted into the follicle. This converts tissue saline locally to sodium hydroxide, which destroys the follicle. Alternatively, the thermolysis technique utilizes an AC current to directly heat and thereby destroy the papilla. Some clinicians utilize a

combination approach of these two electrolysis techniques. All electrolysis methods treat a single follicle at any time, in a painful procedure which can require analgesia. Disposable needles are used in this non-permanent, time consuming, multiple treatment technique.

Several contemporary photonics techniques have been evaluated. In 1993, Thermotrex Corporation was assigned two Hair Removal Device and Method patents (U.S. Pat. Nos. 5,226,907 and 5,425,728) based on the use of an externally applied chromophore to enhance local absorption of laser light. In these patents, a topically applied substance is said to penetrate to the full depth of the root of the follicle. The substances cited include permanent hair dyes, suspensions of carbon particles and photosensitizing compounds. A subsequent application of laser light is said to induce a photothermal reaction which destroys the follicle and a surrounding tissue area.

A second technique has been studied and reported by Drs. Melanie Grossman and Rox Anderson whereby single high energy normal mode Ruby laser pulses are applied to the skin in the absence of an externally applied chromophore. No issued patent has been awarded covering this work. In this method, the optical target is the melanin within the inner cortex layer and the pigment-bearing melanocytes lining the follicle. High fluences of up to 60 J/cm^2 are utilized in large spot sizes, with short pulse widths of the order of 150 μ sec and a wavelength of 694 nm. This technique employs a number of natural phenomena to enhance effect on the deep follicular component. A large applied spotsize and high fluence allow for maximum depth of penetration. Concurrent cooling spares bulk tissue structures from the edema and general damage which can result from the use of fluences of this magnitude. Intimate index-matched contact of the custom handpiece with the tissue minimizes reflection loss. However, the short pulse widths used in this approach are unlikely to efficiently transfer heat to the entire follicular structure. The Ruby laser is not readily capable of the requisite millisecond-domain pulses necessary to effect a true thermal mechanism.

A third approach, utilizing the Q-Switched Ruby laser, was disclosed by Nardo Zaias in his 1990 U.S. Pat. No. 5,059,192. This patent cited the use of a Q-Switched Ruby laser at 694 nm, with 3-8 mm spotsize and around 8 J/cm^2. Pulsewidth was in the range 30-40 nanoseconds. Light energy administered in such a short pulsewidth will be well retained in the melanocytes lining the follicle. This approach will provide potential for melanocyte destruction and perhaps permanent depigmentation or destruction of the hair, but likely will not kill the follicle itself, since the pulsewidth is insufficiently long to conduct heat away from the targeted melanin granules.

Other approaches have been described. In 1967, U.S. Pat. No. 3,538,919 was filed by R. Meyer. Meyer cited the placement of a fiber directly into the follicle into which a total of 30-40 J/cm^2 of light was subsequently launched. This fluence was administered over a period of 1-2 milliseconds, preferably by a normal mode Ruby or Nd:YAG laser. Use of a 50 μm fiber was cited. This fiber diameter would theoretically fit into a 100 μm follicle containing a 50 μm hair, but with some difficulty. Also, the technique would be time consuming to administer, on a single hair-by-hair process.

In 1970, Richard Harte filed U.S. Pat. No. 3,693,623, which also cited the placement of a fiber directly into each follicle to be destroyed. The light source here was a xenon lamp, which applied up to 3 mJ to each follicle, in an interval of less than 3 msec. This technique again addresses each hair individually in a tedious and difficult to administer process.

In 1981, H. Weissman filed a patent, later granted as U.S. Pat. No. 4,388,924. This cited the devitalization of hair by the specific destruction of the papillary blood supply. A narrow beam from an Argon laser was directed onto the tissue. This light was said to be absorbed by the papillary plexus, causing heating and coagulation. Multiple 20-30 millisecond exposures from a 0.5-2.5 Watt beam were cited. The hair was subsequently tweezed from its follicle. This method suffers again from the individual hair-by-hair approach, which is time consuming. Also, the selective destruction of the papillary plexus is unlikely to be practical using a narrow beam Argon laser, with its limited

penetration depth capabilities, since this supply resides at several millimeter depth and is shielded by the overlying follicular structure. Indeed, no vascular specific lasers are likely to exhibit adequate dermal penetration.

In 1984, A. Sutton filed a patent, later granted as U.S. Pat. No. 4,617,926. This provided for the use of a fiber without a core, into which an individual hair slides by 2-3 mm, completing the waveguiding action. Different probes were cited, and about 1 Joule of energy launched into the fiber, from an unspecified laser source. In an alternative embodiment, the fiber is sharpened and inserted directly into the follicle. This technique is time consuming and tedious and is likely to result in rapid probe destruction.

There is a need for a high power, diode based laser system with fiber optical delivery. There is a further need for a stacked linear array with improved beam quality. Another need exists for a stacked linear array that can be coupled to commercially available flexible fibers. Still another need exists for a stack linear array that can be used in medical, industrial and scientific applications.

SUMMARY OF THE INVENTION

Accordingly, an object of the invention is to provide an optical assembly for a stack of diode linear arrays to produce a single line source.

Another object of the invention is to provide an optical assembly of one or more stacks of diode linear arrays with array producing a single line source.

Yet another embodiment of the invention is to provide an optical assembly of one or more stacks of diode linear arrays coupled to a plurality of optical fibers.

Still another object of the invention is to provide an optical assembly using one or more stacks of diode linear arrays producing reformatted single line sources with an improved overall m^2.

A further object of the invention is to provide an optical assembly using one or more stacks of diode linear arrays producing reformatted single line sources with improved symmetry.

Another object of the invention is to provide an optical assembly with one or more stacks of diode linear arrays coupled to a handpiece.

These and other objects of the invention are achieved an optical assembly with a stack of diode linear arrays. The stack of diode linear arrays includes a plurality of diode linear arrays that produce a plurality of line output beams. A plurality of microlenses are positioned adjacent to the plurality of diode linear arrays. The microlenses collimate and steer the plurality of line output beams to form a first single line source.

In another embodiment of the invention, the optical assembly includes two or more stacks of diode linear arrays. Each of an array is coupled to an optical fiber.

In yet another embodiment of the invention, optical elements are included to create reformatted single line sources with an improved overall m^2.

In still another embodiment of the invention, the optical assembly includes one or more stacks of diode linear arrays, one or more optical fibers that are each coupled to a stack, optical elements to create the reformatted single line sources and a handpiece coupled to distal ends of the optical fibers.

BRIEF DESCRIPTION OF THE FIGURES

Figure 1 is a schematic diagram of an optical assembly of the present invention that includes a stack of diode linear arrays positioned adjacent to a plurality of microlenses.

Figure 2(a) is a schematic diagram of the optical assembly of Figure 1 in combination with lens and an optical fiber.

Figure 2(b) is a schematic diagram of an embodiment of an optical assembly of the present invention with two stacks of diode linear arrays with microlenses.

Figure 3 is a schematic diagram of the output beam from the embodiment of Figure 2(b) where the output beam is reformatted into two stacked beams.

Figure 4(a) is a schematic diagram illustrated the slicing and stacked on the single line source from the optical assembly of Figures 1, 2 or 3.

Figure 4(b) is a cross-sectional view from Figure 4(a) illustrated the relationship of the two mirrors that slice and stack the single line source.

Figure 4(c) is a perspective view of one of the mirrors from Figure 4(a) illustrated the cut angle of an edge of the mirror.

Figure 5 illustrates an embodiment of the optical assembly of Figure 1 with the inclusion of a prism array to create a reformatted and stacked output beam.

Figure 6 illustrates an embodiment of the optical assembly of Figure 1 with the inclusion of a polarizing cube and a half-wave plate to create the reformatted output beam.

Figure 7 illustrates an optical assembly of the present invention that includes three diode linear arrays each coupled to a separate optical fiber.

Figure 8 illustrates different geometric arrangements of multiple optical fibers utilized with the optical assembly of the present invention.

Figure 9 illustrates an embodiment of an optical assembly of the present invention that includes two optical fibers and a single set of optical elements to create a reformatted single line source that is launched into an optical fiber.

Figure 10 is a schematic diagram of an optical handpiece that incorporates the optical assembly of Figure 1.

DETAILED DESCRIPTION

Referring now to Figure 1, an optical assembly 10 includes a stack of diode linear arrays 12 which includes a plurality of individual stacked diodes 14. Each diode 14 produces a line output beam 15. In one embodiment, the individual diodes 14 can be 200 μm emitters on 400 μm centers forming a linear diode array 10 mm long and 1 μm high available from OptoPower Corporation, Tucson, Arizona. One example of a stack 12 is ten of the linear arrays described in the preceding sentence, each mounted on a "monsoon plate" which

water cools the individual diodes. This stack is 10 mm wide, 20 mm high with a vertical spacing of 1.8 mm between linear arrays.

Individual stacked diodes 14 are separated by a gap 16. Because of gaps 16, the fill factor of diode stack 12 is less than 100%. The fill factor can be increased by expanding output beams 15 and collimating in the vertical direction.

The m^2 of each stack 12 is not the same in both the horizontal and vertical directions. By way of example, if there are ("N") diodes 14 in stack 12 with a height of 1μm and a spacing ("S") of about 2μm, m^2 in the vertical for the entire stack 12 is as follows:

$$m^2_{\text{(total in the vertical)}} = m^2_{\text{(vertical for each diode)}} (S \times N). \qquad \text{Equation (1)}$$

m^2 in the vertical is poor because the fill factor is low. In this example the fill factor is about 1/2000.

Coupled to each diode 14 in stack 12 is a microlens 18. A suitable microlens 18 is commercially available from LEMO, Frankfurt, Germany and Blue Sky Research, Montana. Microlenses 18 can be plano/convex cylinder lenses, molded aspherics and un-clad fibers. Microlenses 18 can be physically attached to individual diodes 14 by gluing, mounting on a mechanical structure with flexure mounts or push/pull screws to align and lock the lenses in the position, and the like.

Microlenses 18 collimate and steer the plurality of line output beams 15 in each stack 12 to form a single line source 20. Optionally positioned adjacent to stack 12 is a cylinder lens 22 that collimate the plurality of line output beams 15 into the single line source 20. Cylinder lens 22 can be either a negative or positive lens, depending on its positioning to a crossing of the plurality of line output beams 15.

Gaps 16 are eliminated with the creation of single line source 20. The fill factor of single line source 20 is about 100%. Single line source 20 has an overall m^2 that is improved in one of the horizontal or vertical directions. In the

example given above, the fill factor of stack 12 is improved from 1/2000 to 1 by the creation of single line source 20.

In various embodiments, single line source 20 can have dimensions of 0.5-5 mm high and 10-20 mm wide.

In one embodiment illustrated in Figure 2(a), an optical fiber 24 is included and positioned to receive the launching of single line source 20 into a proximal end 26 of the first optical fiber 24. In various embodiments, the dimensions of single line source 20 and proximal end 26 can be in the range of 5-20 mm square. In another embodiment, a lens 27, such as a molded aspheric lens, is included. In this embodiment, the dimensions of proximal end 26 are greater than or equal to 1.5 mm.

Single line source 20 can be launched into proximal end 26 of optical fiber 24 at a numerical aperture approaching a limiting numerical aperture of the first optical fiber. One example of the relative numerical apertures is in the range of 0.2-0.7.

Referring now to Figure 2(b) optical assembly 10 includes first and second stacks of diode linear arrays 12 and 13 each producing single line sources 20 and 21 respectively that are joined to form a continuous line of higher power than the embodiment of Figure 2(a).

Single line source 20 can have an m^2 larger in one of a horizontal or vertical direction than the other. In order to improve the launching into optical fiber 24, single line source can be reformatted with an improved overall m^2. In Figure 3, single line source 20 is shown as being reformatted into two stacked beams with an overall height of 200-1500 μm. In Figure 3, the focused beams are shown as being non-overlapped. However, the stacked beams can be overlapped to form a single beam that has half the overall dimension and an increased numerical aperture. It will be appreciated that single line source 20 can be reformatted into more than two stacked beams. When reformatted single line source 28 is sliced once and stacked into two beams it can be focused into a 1.5 mm optical fiber 24. If reformatted single line source 28 is sliced twice and stacked into three beams it can be focused into a 1 mm optical fiber 24. If

reformatted single line source 28 is sliced three times and stacked into four beams it can be focused into a 0.75 mm optical fiber 24. Single line source 20 is reformatted and sliced up so that reformatted single line source 28 becomes symmetrical. In this embodiment, reformatted single line source 28 has an improved brightness level equal to the ratio of proximal end 26 to stack dimensions. This can be an improved brightness level of 10 to 100 fold over the original stack. Various optical elements can be used to improve the focusability of single line source 20 into optical fiber 24 including but not limited to a pair of lenses, a prism array, a half wave plate, polarization cube, a prism with multiple reflection faces, and the like.

In another embodiment illustrated in Figures 4(a)-4(c), single line source 20 is incident on a first mirror 30 and a second mirror 32. Mirrors 30 and 32 splice single line source 20 and stacks it. One-half of single line source 20 is not reflected by either mirror 30 or 32 and passes through. The other half of single line source 20 is reflected off of mirror 30 to mirror 32 and is then stacked along with the first half of single line source 20. Mirrors 30 and 32 can be formed from a unitary construction. In this embodiment, there is less loss and is particularly suitable for high power. Mirrors 30 and 32 have a tilt relative to each other. Because of the tilt, first mirror 30 has a non-perpendicular, angle cut first edge. Because of the tilt of the two mirrors 30 and 32, the cut edge of mirror 30 causes single line source 20 to see a straight edge. Without the cut, the effect would be a single line source 20 with a edge and the creation of a wider apparent beam as well as an increase in m_h^2. The cut edge of mirror 30 reduces m_h^2. Additionally, in this embodiment, more than two mirrors can be used to create three or more reformatted stacked beams 28. Alternatively, the cut edge of mirror 30 can be angled to reshape the reflected beam into a profile more closely matching optical fiber 24. When multiple reflectors are used, the cross-section of the sliced and stacked beams can be shaped and/or pieced together to match the cross-section of optical fiber 24.

Referring to Figure 5, a prism array 34 has two or more reflective surfaces 36 which serve to redirect single line source 20 to a reformatted single

line source 28 as disclosed in U.S. Patent Application, S.N., 09/229,461, filed January 12, 1999, fully incorporated herein by reference. Prism array is positioned on a mount 38 with a longitudinal axis 40. Prism array 36 is positioned just above a mount surface 42 by a backing plate 44.

Another embodiment for created reformatted single line source 28 is shown in Figure 6. In this embodiment, reformatted single line source 28 is a single beam that is not stacked. A half-wave plate 46 and a turning mirror 48 are provided. One-half of single line source 20 is incident on a polarizing cube 48. The other half of single line source is incident on half-wave plate 46 and turned 90°. In this embodiment, single line source has an improved m^2 at the expense of polarization that is enhanced using prism array 34 of Figure 5.

Referring now to Figure 7, a plurality of stack of diode linear arrays 12 can be used. As illustrated in Figure 7, three stacks 12, 50 and 52 are shown. It will be appreciated that the present invention can include any number of stack diode linear arrays. Each stack 12, 50 and 52 produces a single line source 20, 54 and 56 that is launched into an optical fiber 24, 58 and 60 respectively. Single line sources 20, 54 and 56 are reformatted with one or more of the optical elements illustrated in Figures 4(a)-6. Distal ends 62, 64 and 66 of optical fibers 24, 58 and 60 are coupled to a handpiece 68. A plurality of collimating lenses 65, 67 and 69 collimate the outputs from optical fibers 24, 58 and 60. A focusing lens 71 can be positioned in handpiece 68 that focuses reformatted single line sources 20, 54 and 56 to a single point 72 with dimensions in the range of 1-5 mm to 10 mm. Handpiece 68 is dimensioned and has a weight that permits the surgeon to readily hold handpiece 68 for long treatment periods of time without fatigue. Handpiece 68 can have a diameter of 0.25-2 in., a length of 2-8 in. and a weight of 2- 8 oz.

Any number of optical fibers can be used with the present invention with their distal ends arranged in a variety of different geometric configurations. Referring now to Figure 8, depending on the arrangement of the distal ends of the optical fibers, a linear, rectangular, square, triangular or circular single point 72 can be created.

As illustrated in Figure 9, two or more optical fibers 20 and 58 can use a single set of optical elements to create reformatted single line source 28. Reformatted single line source 28 can then be launched into a single optical fiber 24.

In another embodiment illustrated in Figure 10, stack 12 is coupled to handpiece 68. Stack 12 can be positioned in an interior or at an exterior of handpiece 68.

In one application, optical assembly 10 is used for hair removal. The goal of the treatment is to irreversibly damage the follicular structures while leaving the surrounding normal skin intact and unaffected. In one embodiment, parameters are chosen to provide optimum selectivity of damage to the target tissue only. The damage is thermal in nature, calculated as necessary to effect a degree of controlled conduction to surrounding structures. The epidermis and peri-vascular dermis are spared while damage is administered, in a controlled fashion, uniformly throughout the targeted follicular structures. This is turn minimizes any complications associated with wound formation or unwanted cosmetic outcome. All hairs within the irradiated area are treated simultaneously, eliminating the need for a tedious individualistic approach.

With 1000 W of treatment radiation at about 810 nm typical treatment spot sizes of 10 mm diameter can be used. The spot size can be increased or decreased by varying focusing lens 71 of Figure 7. Additionally, spot size can be changed by varying the distance between distal ends 62, 64 and 66 of optical fibers 24, 58 and 60 and collimating lenses 65, 67 and 69. Further, the surgeon can vary the distance between the treatment site and handpiece 68 to vary the spot size. Spot size variation is used to treat different skin pigmentations.

In another embodiment, a gel can be used on the skin and serve as a heat sink to reduce the thermal diffusion time of the skin. The gel prevents the skin from becoming too hot. Optionally, the gel can include a material that changes color after it has irradiated with treatment light from optical assembly 10. This provides an indicator to the physician where treatment has been delivered and

reduces the chance of overexposing the skin to electromagnetic energy. In another embodiment, the gel changes its opacity to electromagnetic energy when a predetermined amount of electromagnetic energy has been delivered. This reduces the chance of overexposure of the skin to energy and provides a mechanism to meter the correct dosage of energy to damage the hair follicle without damaging the skin.

The gel is not used to actively cool the skin. Instead, the gel provides a heat sink on the skin surface and reduces the skin thermal diffusion time. Light entering the skin can be scattered in a forward direction towards the hair follicles. Back-scattered light moves in the opposite direction and heats the skin. When the angle of incidence of the back-scattered light exceeds the critical angle of refraction, then the light is reflected through the skin layer, becomes trapped and then heats the skin surface. To reduce this phenomena, the gel is used to substantially increase the critical angle of the skin/gel interface. This allows the trapped light to escape and avoids heating the epidermis.

Additionally, optical assembly 10 can be used to treat other conditions including but not limited to psoriasis, warts, wrinkles, smooth skin contour, leg veins, and the like. When leg veins are treated the shape of the treatment area is as illustrated in Figure 8 to provide a linear output beam that matches the profile of the vein.

The foregoing description of a preferred embodiment of the invention has been presented for purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise forms disclosed. Obviously, many modifications and variations will be apparent to practitioners skilled in this art. It is intended that the scope of the invention be defined by the following claims and their equivalents.

What is claimed is:

CLAIMS

1. An optical assembly, comprising:

a first stack of diode linear arrays, each of a diode linear array in the first stack producing a first plurality of line output beams, the first stack of diode linear arrays having a first fill factor; and

a first plurality of microlenses positioned that colliminate and steer the first plurality of line output beams to form a first single line source.

2. The assembly of claim 1, wherein the first single line source has a greater fill factor than the first fill factor.

3. The assembly of claim 1, wherein the first single line source has a fill factor of about 100%.

4. The assembly of claim 1, further comprising:

a lens positioned in the path of the first plurality of line output beams to form the first single line source.

5. The assembly of claim 1, wherein each of a microlens in the first plurality of microlenses is attached to a diode linear array.

6. The assembly of claim 1, further comprising:

a first optical fiber positioned to receive launching of the first single line source into a proximal end of the first optical fiber.

7. The assembly of claim 6, wherein the first single line source is launched into the proximal end of the first optical fiber at a numerical aperture approaching a limiting numerical aperture of the first optical fiber.

8. The assembly of claim 6, wherein the first single line source has a sufficiently small spot size to be launched into the proximal end of the first optical fiber.

9. The assembly of claim 1, wherein the first single line source has an m^2 larger in one of a horizontal or vertical direction than the other.

10. The assembly of claim 1, further comprising:

a second stack of diode linear arrays, each of a diode linear array in the second stack producing a second plurality of line output beams, the second stack of diode linear arrays having a second fill factor, the second stack of diode linear arrays being positioned adjacent to and along a longitudinal axis of the first stack of diode linear arrays; and

a second plurality of microlenses positioned that colliminate and steer the second plurality of line output beams to form a second single line source.

11. The assembly of claim 10, wherein the first and second single line sources connect to form a continuous line source.

12. The assembly of claim 9, further comprising:

a first reflective member positioned adjacent to the first single line source; and

a second reflective member positioned adjacent to the first reflective member, a first portion of the second reflective member being positioned in an optical path of the first single line source to redirect a portion of the first single line source to the first reflective member, the first and second reflective members forming a reformatted first single line source with an improved m^2 along a longitudinal axis of the first line source.

13. The assembly of claim 9, further comprising:

a prism array including a plurality of reflective prism faces that redirect the first single line source and create a reformatted first single line source with an improved m^2 along a longitudinal axis of the first line source.

14. The assembly of claim 12, further comprising:

a first optical fiber positioned to receive launching of the reformatted first single line source into a proximal end of the first optical fiber.

15. The assembly of claim 12, further comprising:

a focusing optic positioned along an optical path of the reformatted first single line source to launch the reformatted first single line source into the proximal end of the first optical fiber.

16. The assembly of claim 14, further comprising:

a handpiece coupled to a distal end of the first optical fiber.

17. The assembly of claim 16, further comprising:

a focusing optic positioned in the handpiece.

18. The assembly of claim 14, further comprising:

a second stack of diode linear arrays, each of a diode linear array in the second stack producing a second plurality of line output beams, the second stack of diode linear arrays having a second fill factor; and

a second plurality of microlenses positioned to colliminate and steer the second plurality of line output beams to form a second single line source.

19. The assembly of claim 18, wherein the second single line source has a greater fill factor than the second fill factor.

20. The assembly of claim 18, wherein the second single line source has a fill factor of about 100%.

21. The assembly of claim 18, further comprising:

a lens positioned in the path of the second plurality of line output beams to form the second single line source.

22. The assembly of claim 18, wherein each of a microlens in the second plurality of microlenses is attached to a diode linear array.

23. The assembly of claim 18, further comprising:

a second optical fiber positioned to receive launching of the second single line source into a proximal end of the second optical fiber.

24. The assembly of claim 23, wherein the second single line source is launched into the proximal end of the second optical fiber at a numerical aperture approaching a limiting numerical aperture of the second optical fiber.

25. The assembly of claim 23, wherein the second single line source has a sufficiently small spot size to be launched into the proximal end of the second optical fiber.

26. The assembly of claim 18, wherein the second single line source has an m^2 larger in one of a horizontal or vertical direction than the other.

27. The assembly of claim 26, further comprising:

a first reflective member positioned adjacent to the second single line source; and

a second reflective member positioned adjacent to the first reflective member, a first portion of the second reflective member being positioned in an optical path of the second single line source to redirect a portion of the second single line source to the first reflective member, the first and second reflective

members forming a reformatted second single line source with an improved m^2 along a longitudinal axis of the first line source.

28. The assembly of claim 24, further comprising:

a prism array including a plurality of reflective prism faces that redirect the second single line source and create a reformatted second single line source with an improved m^2 along a longitudinal axis of the first line source.

29. The assembly of claim 28, further comprising:

a second optical fiber positioned to receive launching of the reformatted second single line source into a proximal end of the second optical fiber.

30. The assembly of claim 29, further comprising:

a focusing optic positioned along an optical path of the reformatted second single line source to launch the reformatted second single line source into the proximal end of the second optical fiber.

31. The assembly of claim 30, further comprising:

a handpiece coupled to a distal end of the first optical fiber and a distal end of the second optical fiber.

32. The assembly of claim 31, further comprising:

a focusing optic positioned in the handpiece to image the reformatted first and second single line sources into a common spot.

33. The assembly of claim 32, wherein the distal ends of the first and second optical fibers are positioned on an arc relative to the focusing optic.

34. The assembly of claim 32, wherein the distal ends of the first and second optical fibers are selectively positioned and distanced from the focusing

to increase a numerical aperture of the reformatted first and second single lines sources into the common spot.

35. The assembly of claim 32, wherein the common spot has a size that is substantially the same as an output from a single optical fiber.

36. The assembly of claim 32, further comprising:

a zoom optical device coupled to the handpiece and providing adjustability of the spot size.

37. An optical assembly, comprising:

a first stack of diode linear arrays, each of a diode linear array in the first stack producing a first plurality of line output beams, the first stack of diode linear arrays having a first fill factor;

a first plurality of microlenses positioned that collimate and steer the first plurality of line output beams to form a first single line source;

a second stack of diode linear arrays, each of a diode linear array in the second stack producing a second plurality of line output beams, the second stack of diode linear arrays having a second fill factor;

a first optical fiber positioned to receive launching of the first single line source into a proximal end of the first optical fiber;

a second plurality of microlenses positioned to collimate and steer the second plurality of line output beams to form a second single line source; and

a second optical fiber positioned to receive launching of the second single line source into a proximal end of the second optical fiber.

38. The assembly of claim 37, further comprising:

a lens positioned along an optical path of the first single line source and along an optical path of the second single line source to produce a combined single line source;

a first lens positioned adjacent to the second combined line source; and

a second lens positioned adjacent to the first lens, a first portion of the second lens being positioned in an optical path of the combined single line source to redirect a portion of the combined single line source to the first lens, the first and second lenses forming a reformatted combined single line source with an improved m^2 along a longitudinal axis of the first line source.

39. The assembly of claim 37, further comprising:

a prism array including a plurality of reflective prism faces that redirect the combined single line source and create a reformatted combined single line source with an improved m^2 along a longitudinal axis of the first line source.

40. The assembly of claim 39, further comprising:

a third optical fiber with a proximal end coupled to the reformatted combined single line source.

41. The assembly of claim 40, further comprising:

a handpiece coupled to a distal end of the third optical fiber.

42. An optical assembly, comprising:

a handpiece;

a first stack of diode linear arrays coupled to the handpiece, each of a diode linear array in the first stack producing a first plurality of line output beams, the first stack of diode linear arrays having a first fill factor; and

a first plurality of microlenses positioned to collimate and steer the first plurality of line output beams to form a first single line source.

43. The assembly of claim 42, wherein the first stack of diode linear arrays is positioned in an interior of the handpiece.

44. The assembly of claim 43, further comprising:

a lens positioned in the interior of the handpiece along a path of the first plurality of line output beams to form the first single line source.

45. The assembly of claim 44, wherein the first single line source has an m^2 larger in one of a horizontal or vertical direction than the other.

46. The assembly of claim 45, further comprising:

a first lens positioned adjacent to the first single line source; and

a second lens positioned adjacent to the first lens, a first portion of the second lens being positioned in an optical path of the first single line source to redirect a portion of the first single line source to the first lens, the first and second lenses forming a reformatted first single line source with an improved m^2 along a longitudinal axis of the first line source.

47. The assembly of claim 46, wherein the first and second lenses are positioned in the interior of the handpiece.

48. An optical assembly, comprising:

a plurality of stacks of diode linear arrays, each of a stack in the plurality producing a plurality of line output beams;

a plurality of microlenses positioned to collimate and steer each of a line output beam to create a plurality of single line sources each of a single line source being associated with a stack of diode linear arrays in the plurality; and

a plurality of optical fibers, each of a proximal end of an optical fiber being coupled to a stack of diode linear arrays in the plurality of stacks.

49. The assembly of claim 48, further comprising:

a plurality of reformatting optical devices, each of a reformatting optical device reformatting a single line source of the plurality of single line sources to create a reformatted single line source with an improved overall m^2.

50. The assembly of claim 49, wherein the plurality of optical fibers is arranged to produce a line output source.

51. The assembly of claim 49, wherein the plurality of optical fibers is arranged to produce a substantially rectangular output source.

52. The assembly of claim 49, wherein the plurality of optical fibers is arranged to produce a substantially square output source.

53. The assembly of claim 49, wherein the plurality of optical fibers is arranged to produce a substantially triangular output source.

54. The assembly of claim 49, wherein the plurality of optical fibers is arranged to produce a substantially circular output source.

55. The assembly of claim 49, wherein each of a distal end of an optical fiber of the plurality of optical fibers is arranged to produce a substantially rectangular output source.

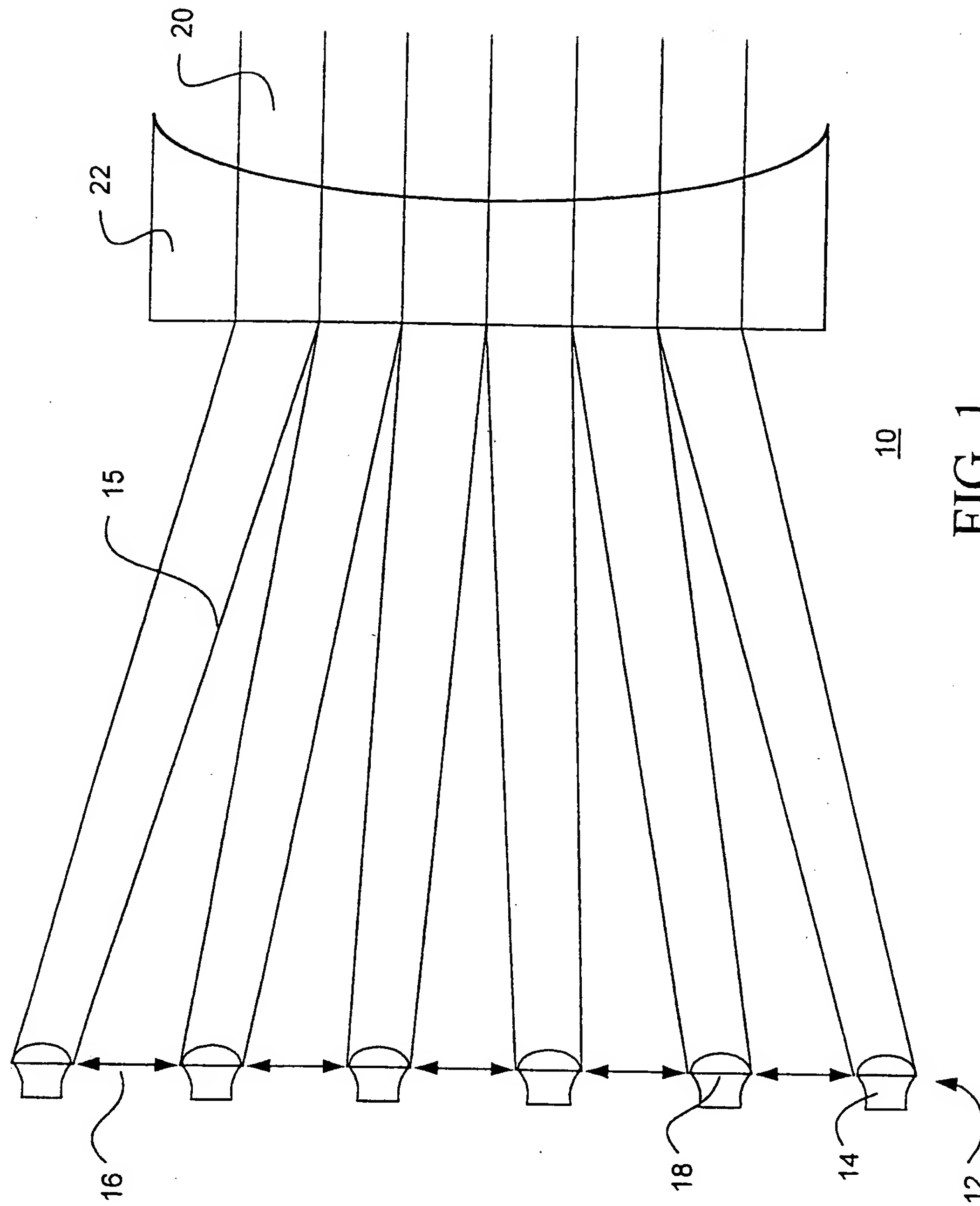


FIG. 1

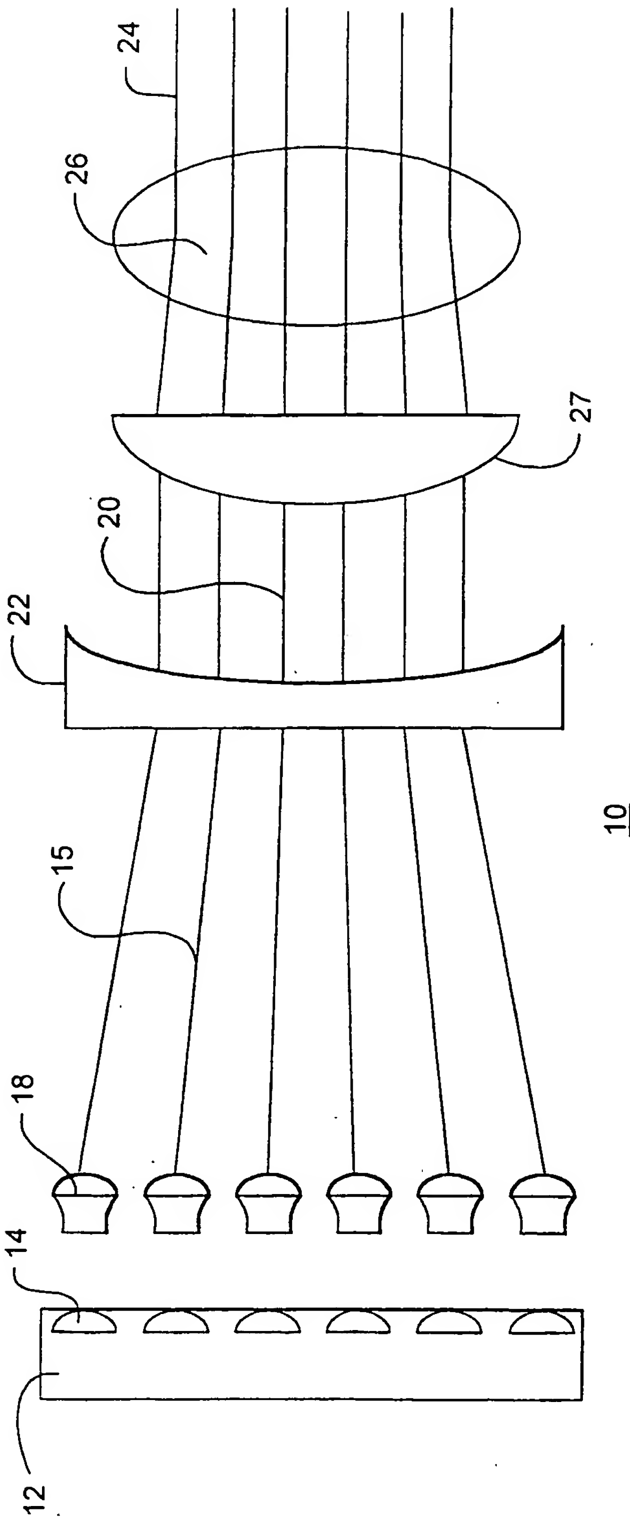


FIG. 2A

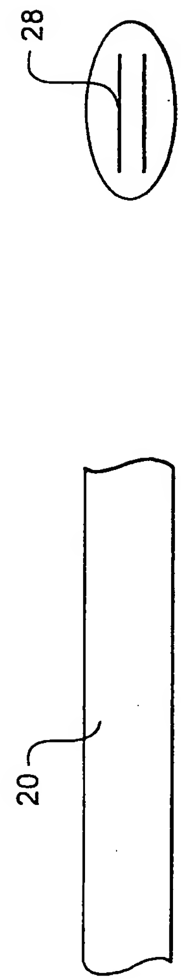


FIG. 3

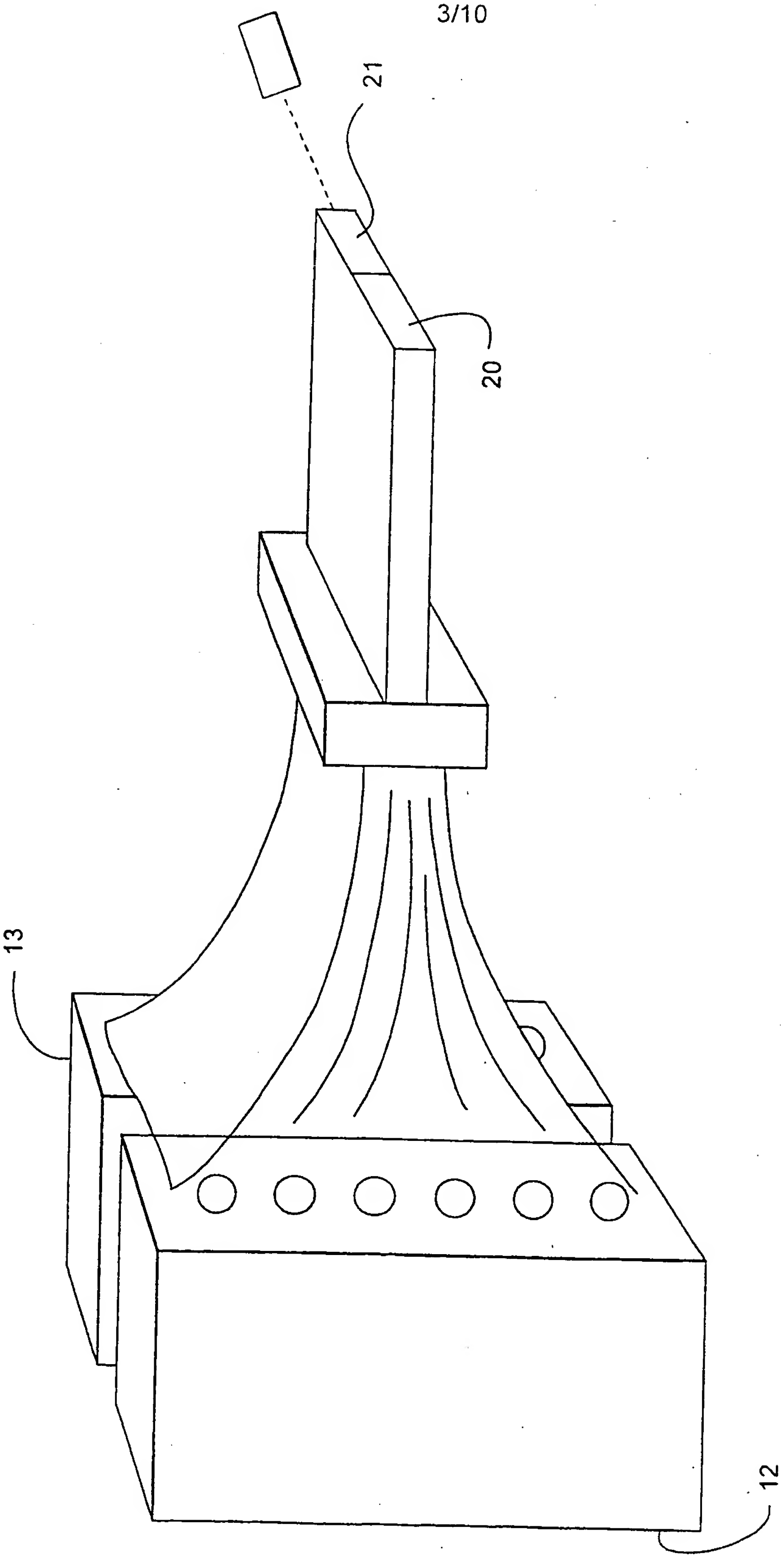


FIG. 2B

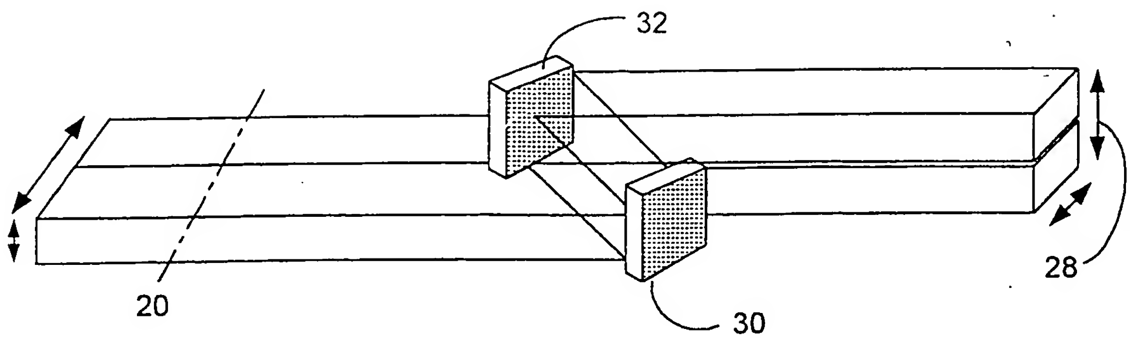


FIG. 4A

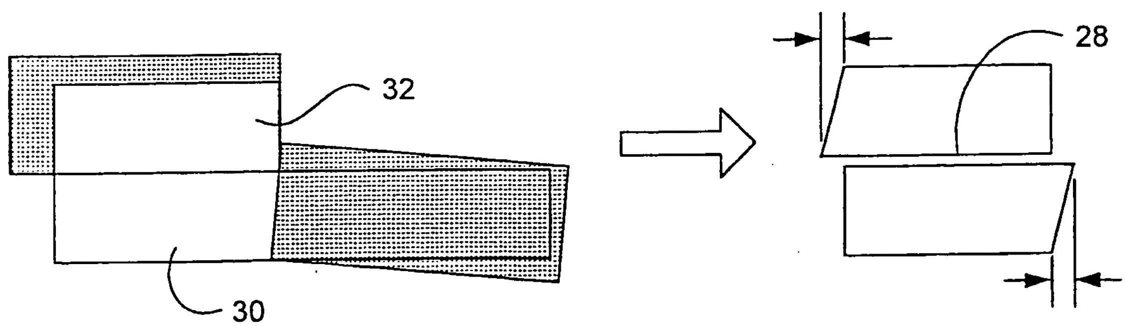
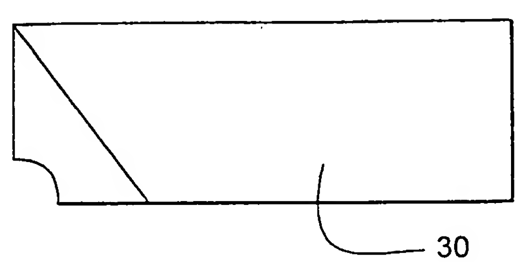


FIG. 4B



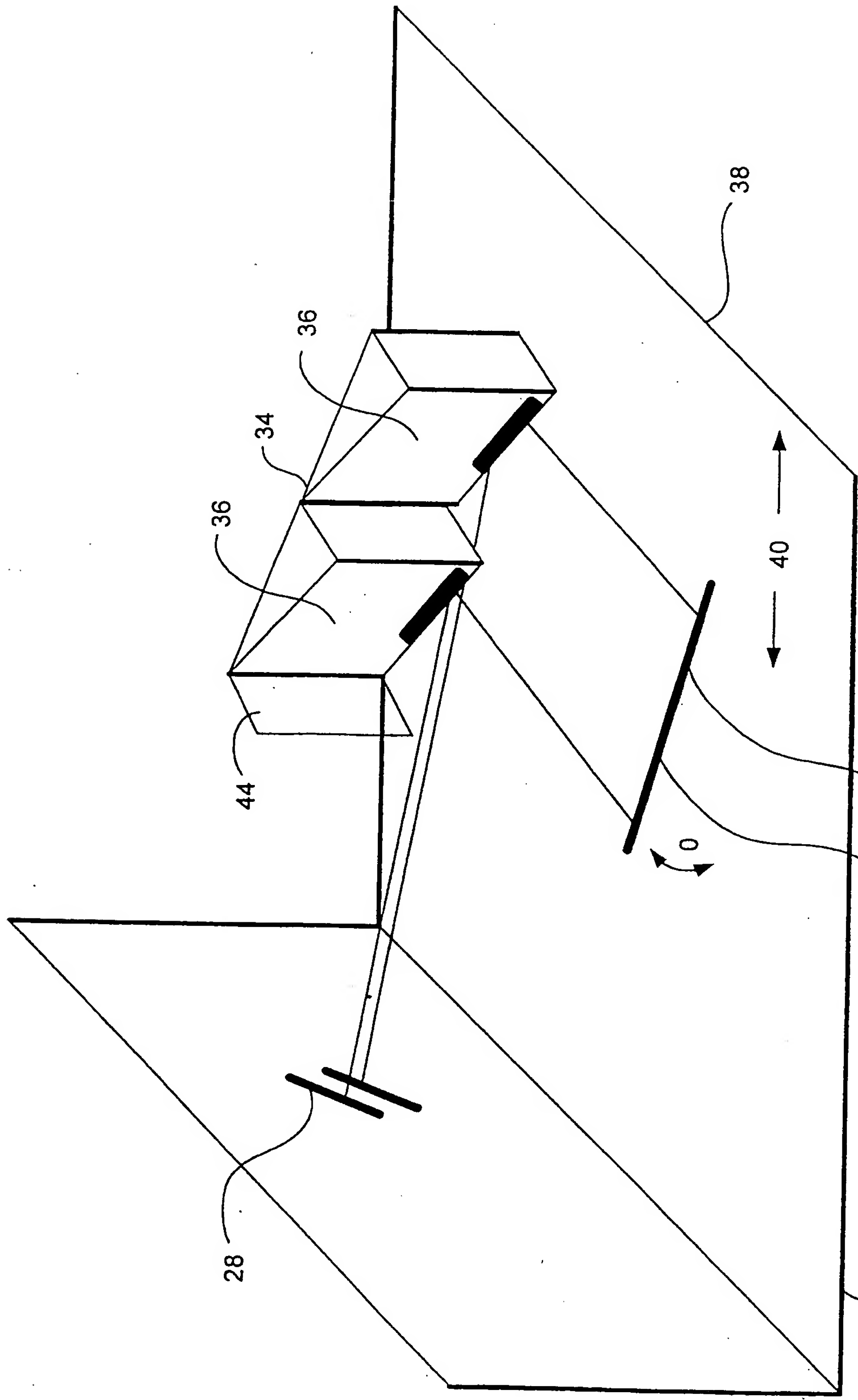


FIG. 5

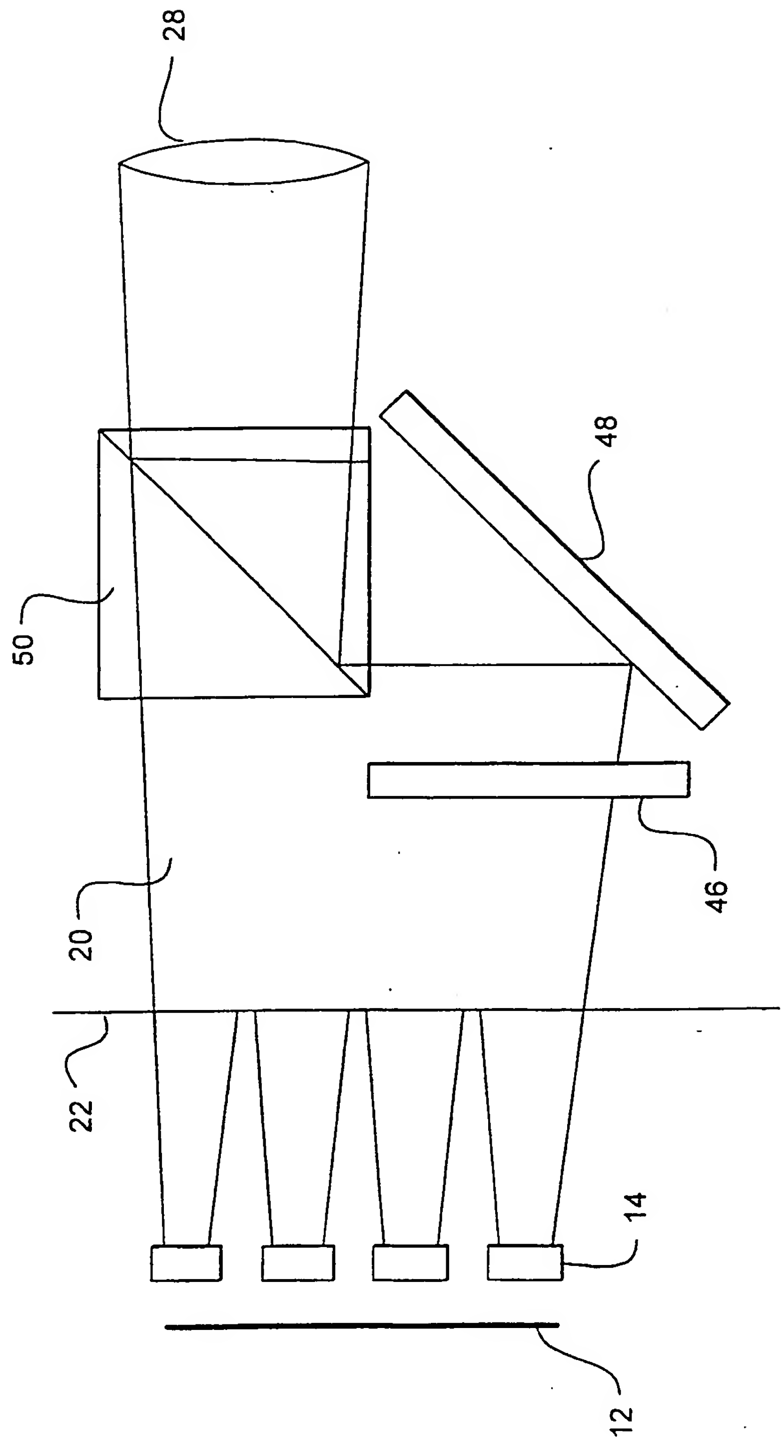


FIG. 6

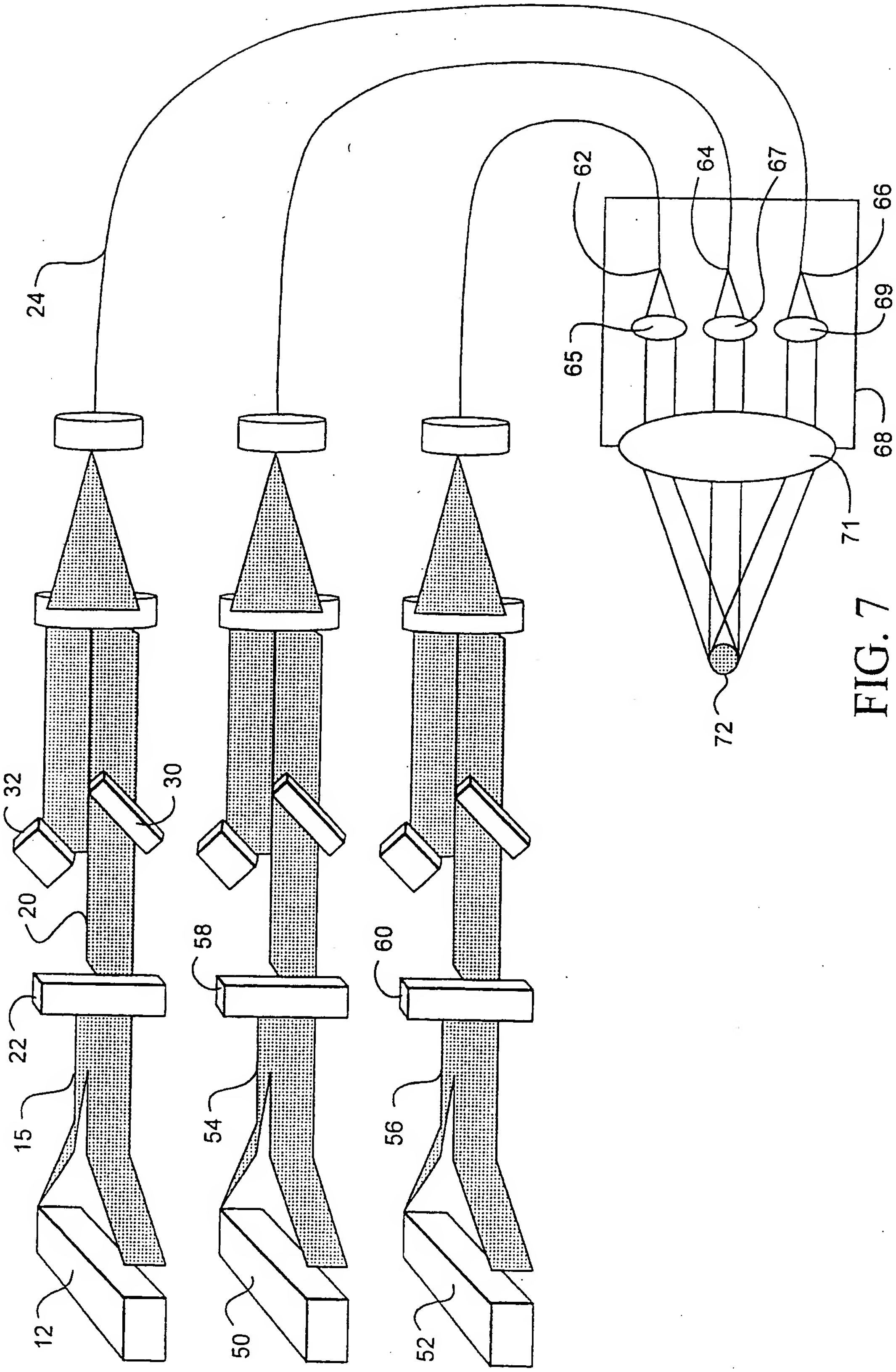


FIG. 7

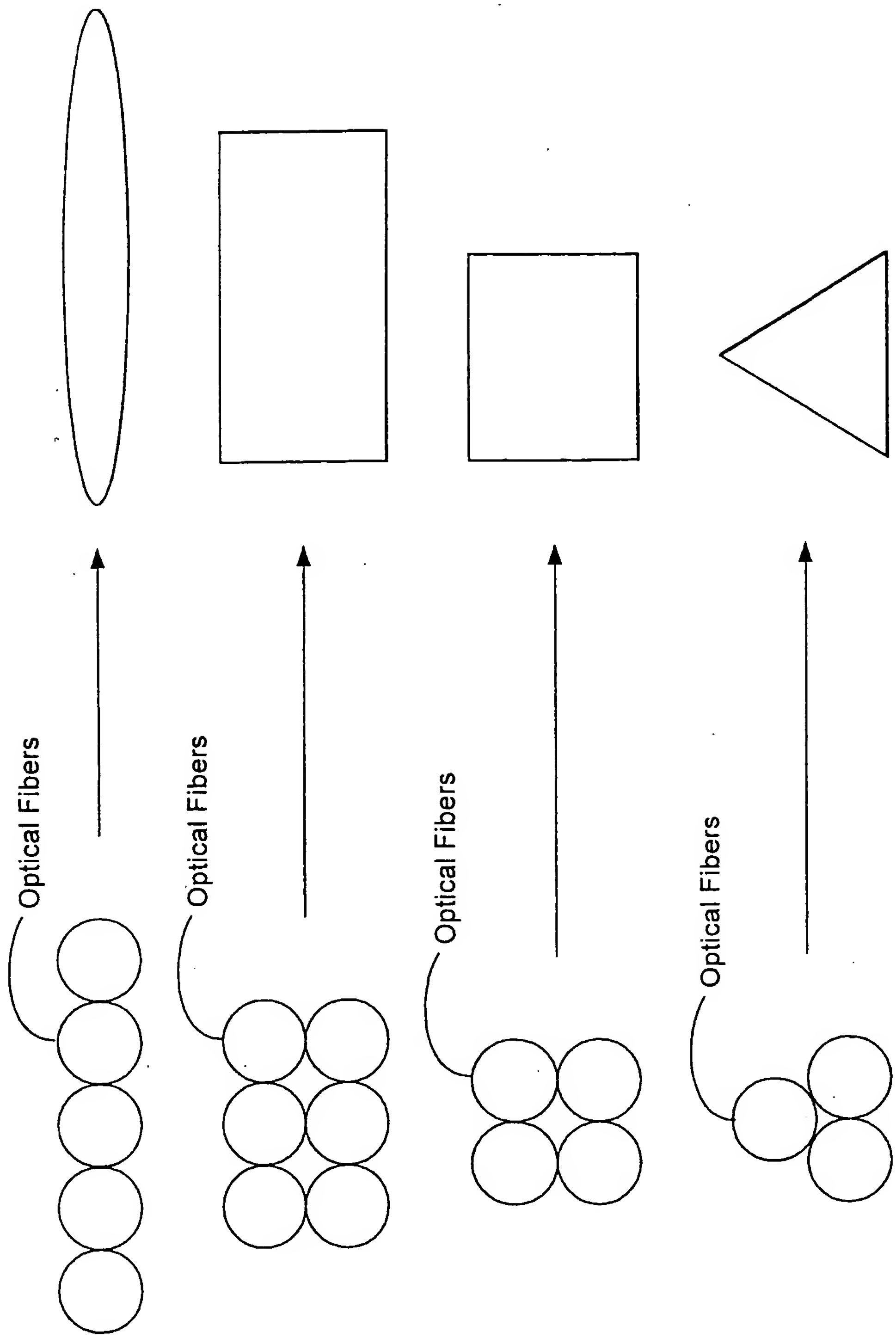

Optical Fibers
Optical Fibers
Optical Fibers
Optical Fibers

FIG. 8

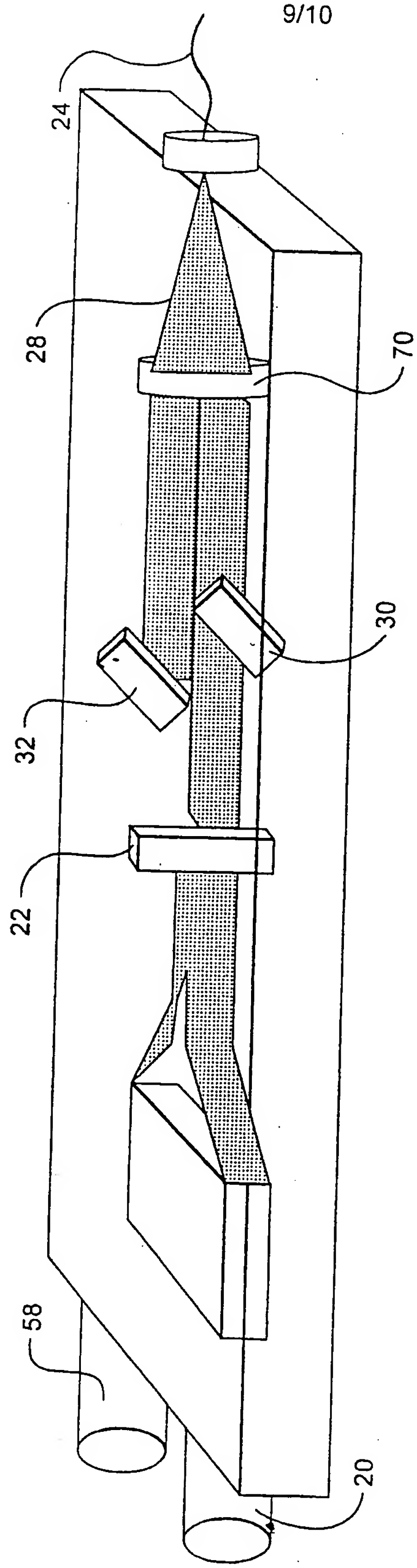


FIG. 9

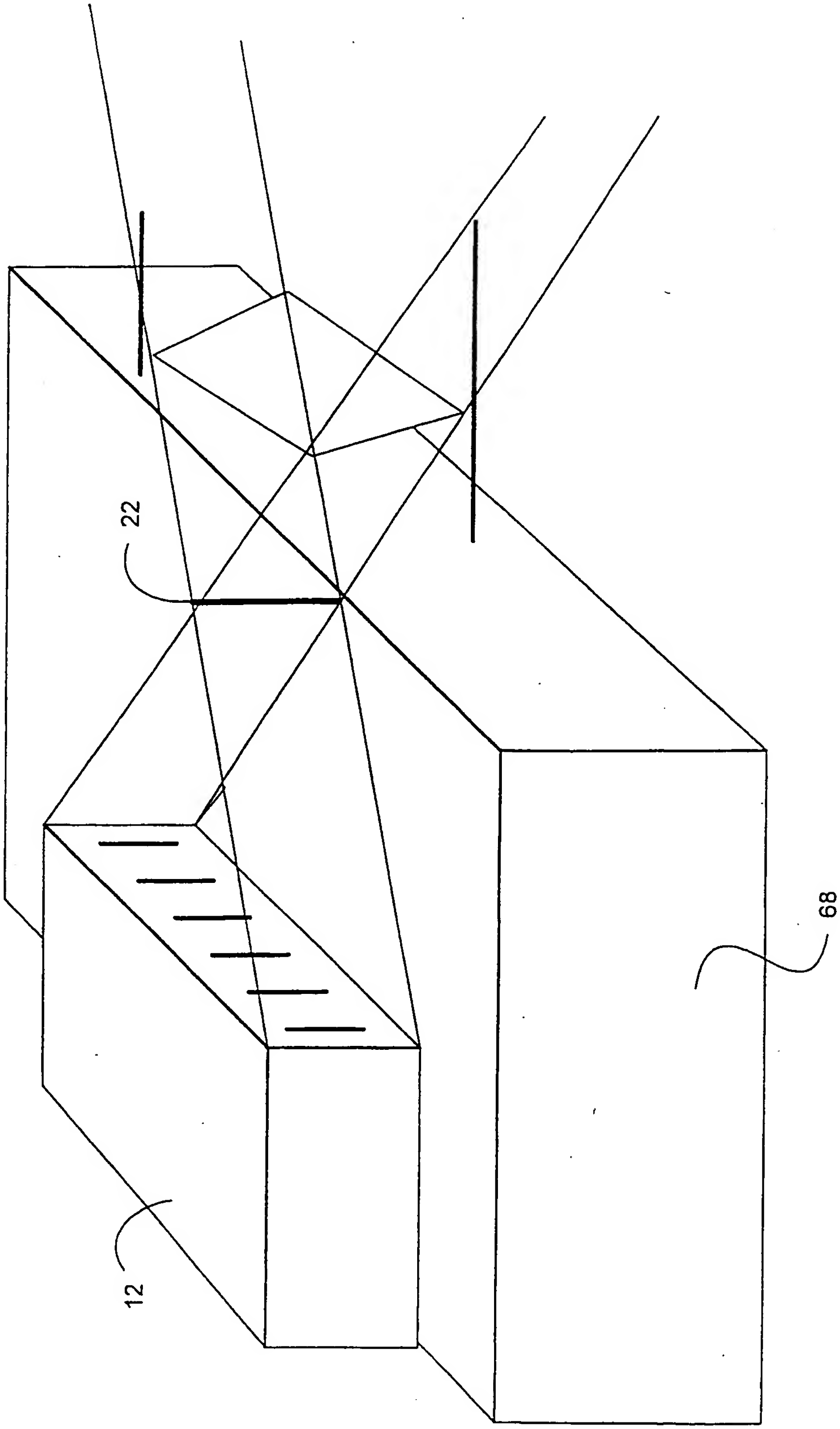


FIG. 10

INTERNATIONAL SEARCH REPORT

Inti ional Application No
PCT/US 00/07510

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G02B6/42 G02B27/14 H01S5/42 A61B18/22

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G02B H01S A61B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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X	US 5 541 951 A (JUHASZ TIBOR ET AL) 30 July 1996 (1996-07-30) abstract; figure 1 column 4, line 4 - line 63	1-8,10, 11,37,48
Y		42-44
X	EP 0 601 485 A (EASTMAN KODAK CO) 15 June 1994 (1994-06-15) abstract; figures 1,4 column 2, line 30 -column 4, line 39	1-8,10, 11,37,48

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
11 August 2000	21/08/2000

Name and mailing address of the ISA	Authorized officer
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INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 00/07510

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

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3

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Information on patent family members

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PCT/US 00/07510

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